Particle Accelerators and Cosmology

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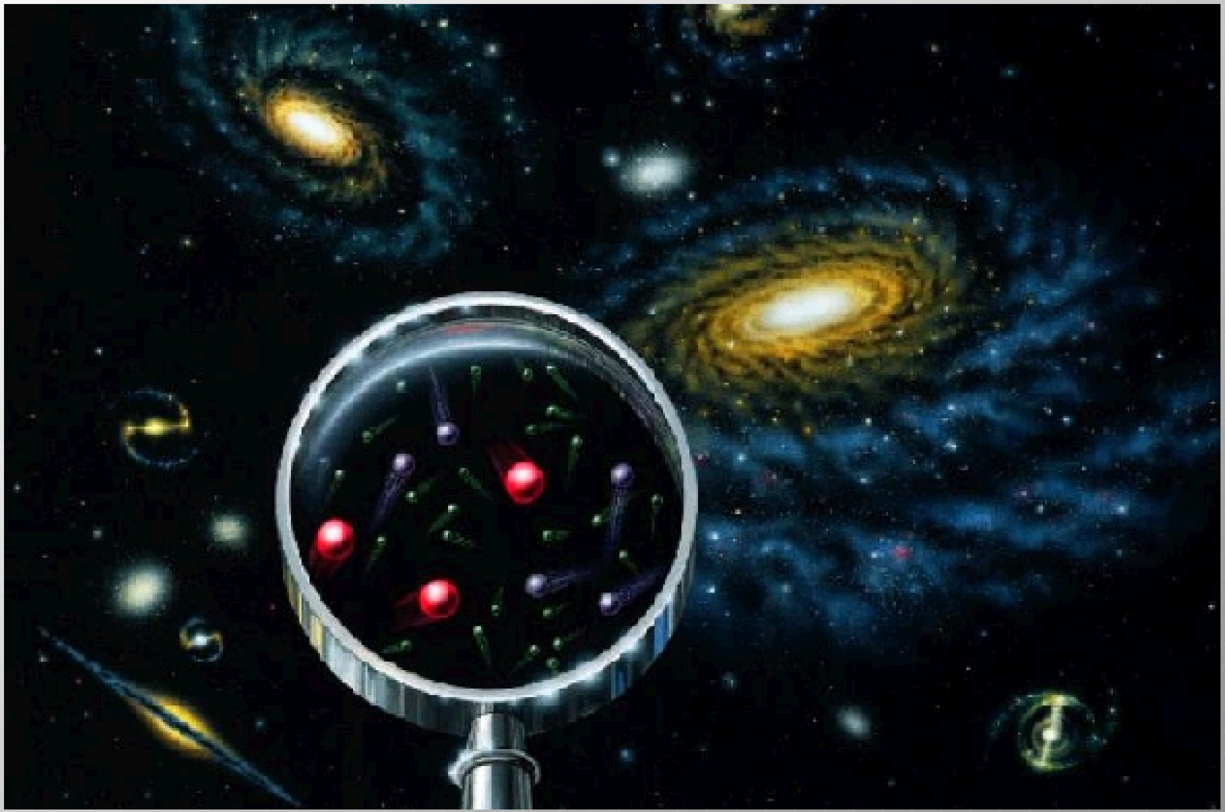
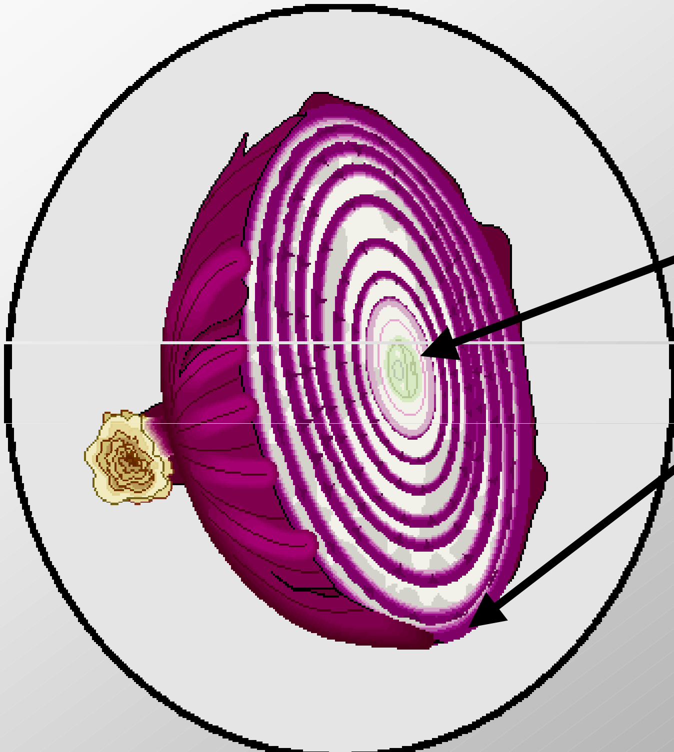
COSMO-02

Quarks to the Cosmos



how remarkable!

tears of the antireductionists

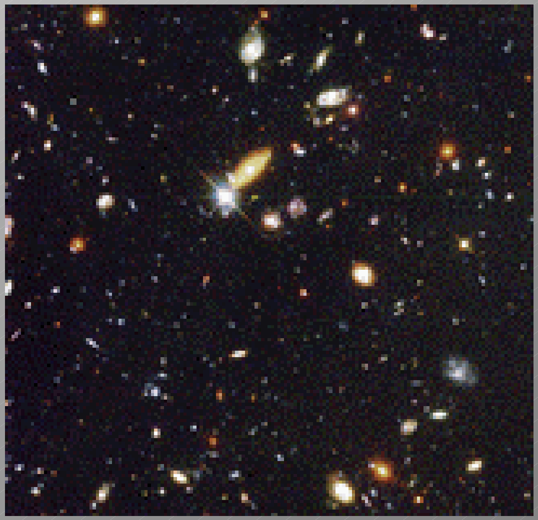


physics on the tiniest scales informs us about physics on the very largest scales, and vice-versa.

physics is not an onion!

a puzzle:

you don’t need the Standard Model
to predict the number of legs on a cockroach



but do you need the Standard Model
– and more -
to understand the cosmos.

the quarks to the cosmos connection exists because of two remarkable facts:

- **gravity is weird**
- **the universe is weird**

gravity is weird

effective field theory says that high energy physics is irrelevant for low energy physics – it can be replaced by matching conditions + operators suppressed by powers of (low momenta)/(big mass scales)

by this argument, gravity should be irrelevant for large scale physics!

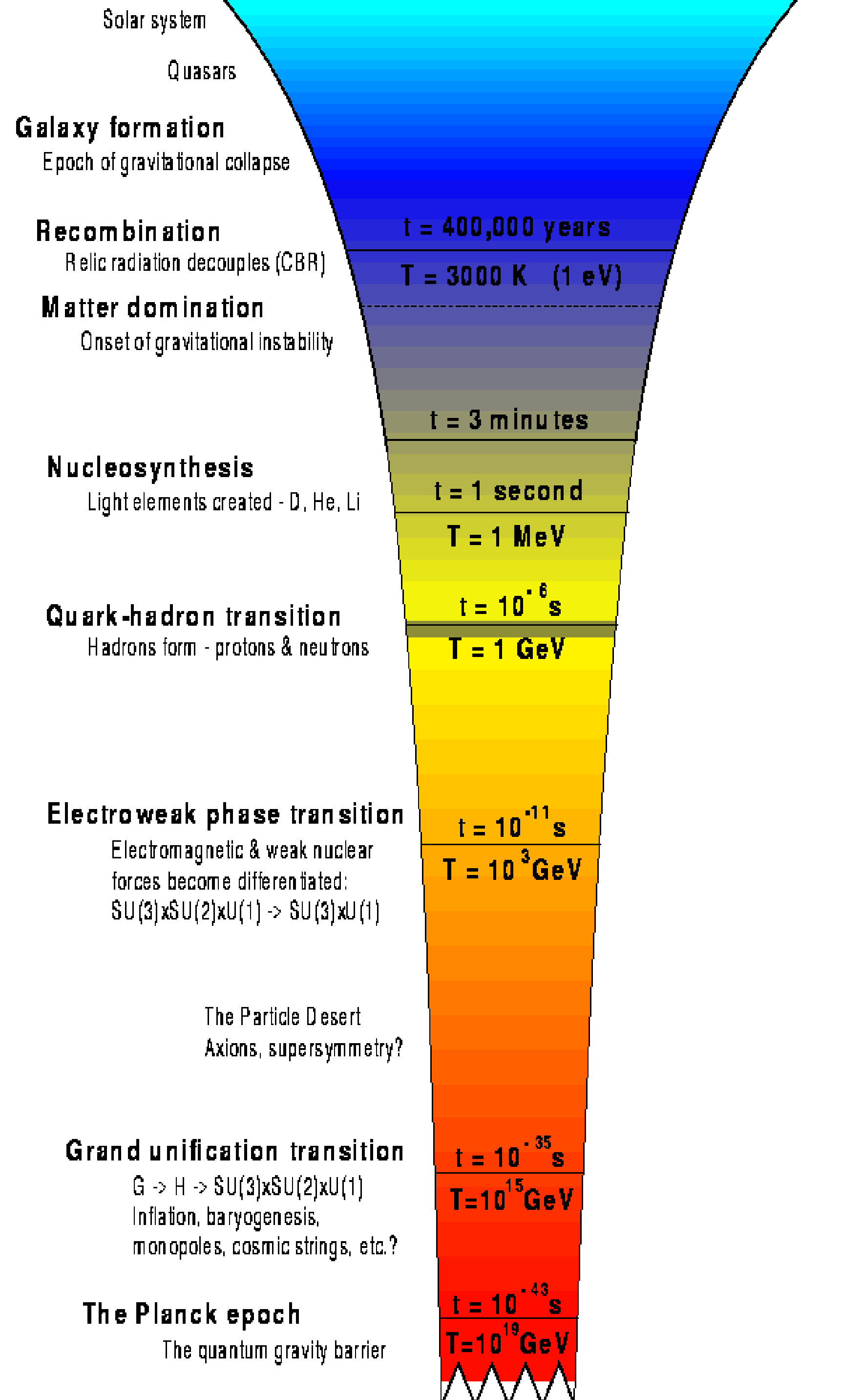
gravity is weird

but in fact gravity is a long-range force with no screening

so on large scales it actually dominates.

the universe is weird

because the universe is large, homogeneous, transparent, … we can reconstruct its history



particle accelerators
the program for this decade

five main activities in HEP:

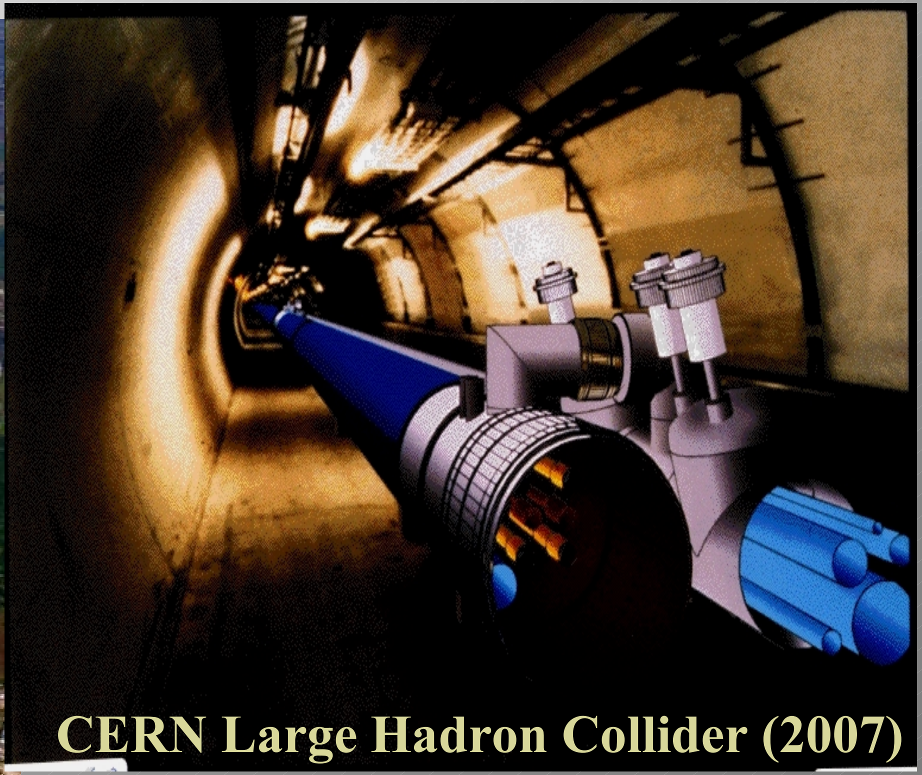
- energy frontier colliders
- heavy quark factories
- neutrino beams
- rare processes
- precision measurements

all of them important for cosmological questions

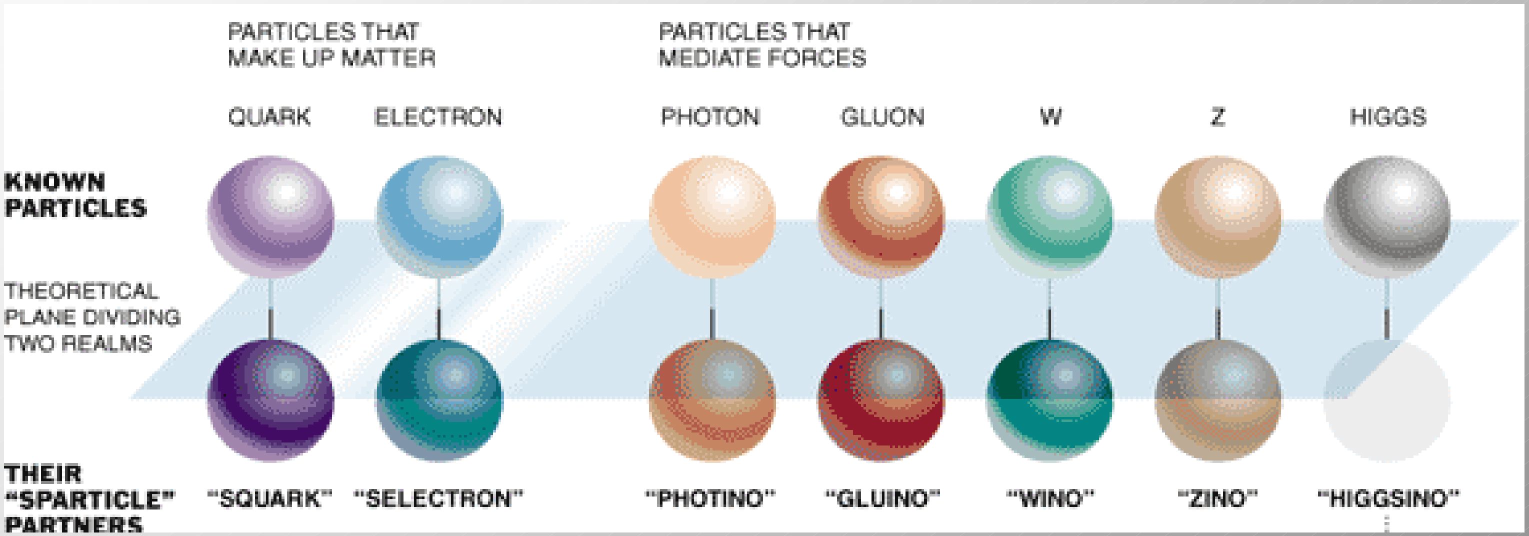
energy frontier colliders

explore the TeV energy scale

what are we looking for?



supersymmetry



susy is not a model

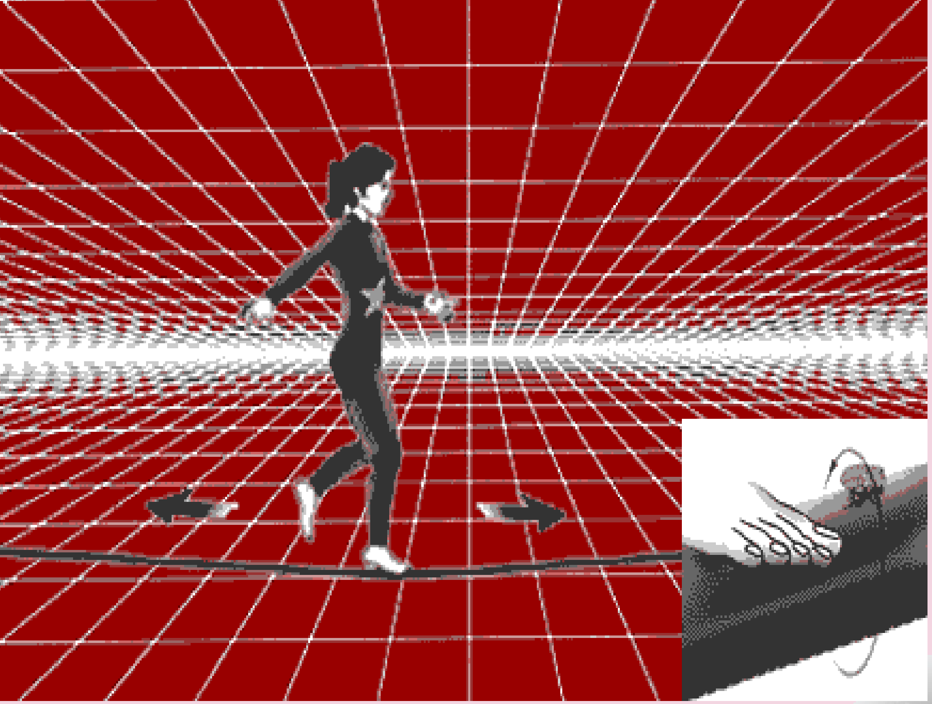
susy is a spontaneously broken spacetime symmetry

supersymmetry

Tevatron mass reach: 400 – 600 GeV for gluinos,
150 – 250 GeV for charginos and neutralinos
200 – 300 GeV for stops and sbottoms

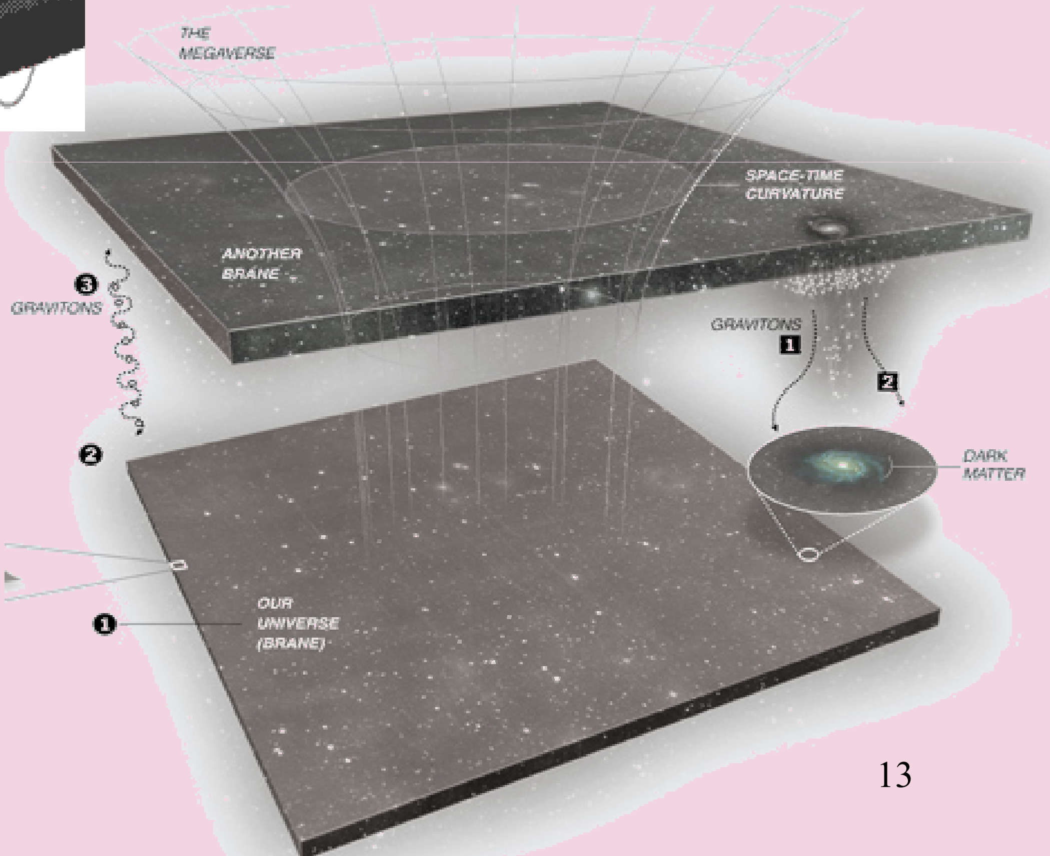
LHC reach: 1 – 3 TeV for almost all sparticles

If susy has anything to do with generating the electroweak scale, we will discover sparticles soon.



extra dimensions

look for graviton production with M* suppressed couplings



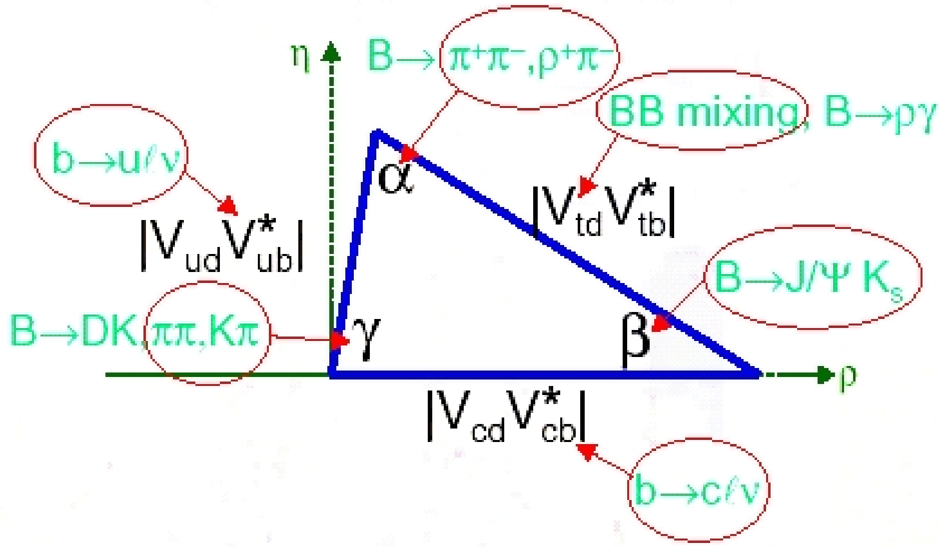
Tevatron reach:
M* ~ 1 – 2 TeV

LHC reach:
M* ~ 5 – 7 TeV

heavy quark factories

BaBar, Belle, CLEO, CDF, D0, LHC-b, BTeV,…

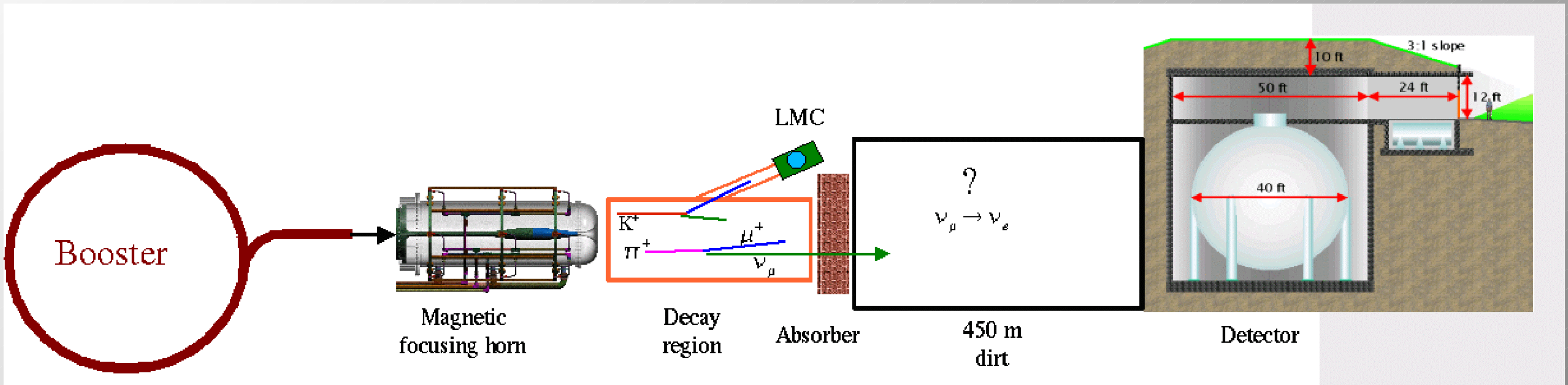
big question: what are the sources of CP violation?



neutrino beams

MiniBooNE, NUMI/Minos, CNGS, JHF, …

high intensity, high purity, known composition



MiniBooNE neutrino beam

precision measurements

the anomalous magnetic moment of the muon can be measured very precisely; it is sensitive, through loop effects, to new particles like smuons and charginos

The Brookhaven g-2 experiment has reported surprising results:

if this is new physics, it is probably susy, and the Tevatron will confirm it.

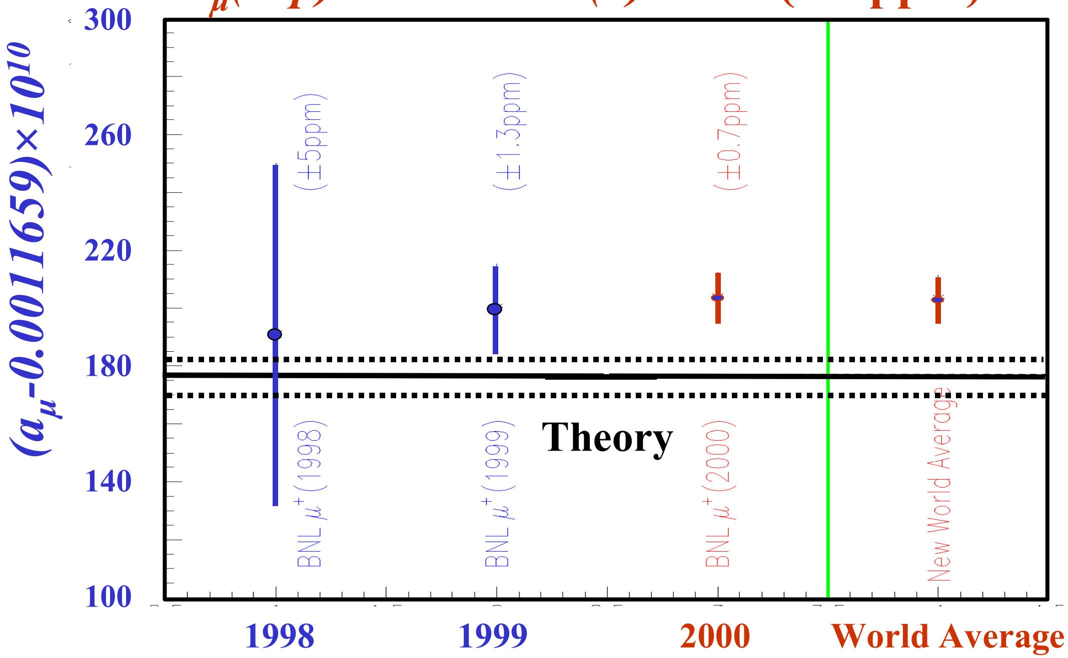
Results

From the Data of 2000:

$a_\mu(exp)=11\ 659\ 204(7)(5)\times 10^{-10}$ **(0.7 ppm)**

Exp. World Average:

$a_\mu(exp)=11\ 659\ 203(8)\times 10^{-10}$ **(0.7 ppm)**



if it is not new physics, it constrains susy models significantly

particle accelerators
the program for this decade

cosmology questions that we attack directly:

- **what is the dark matter?**
- **what is going on with baryo/lepto genesis?**
- **are there effects of extra dimensions at accessible scales?**

Dark Matter

CDM candidates that can be produced and identified at colliders:

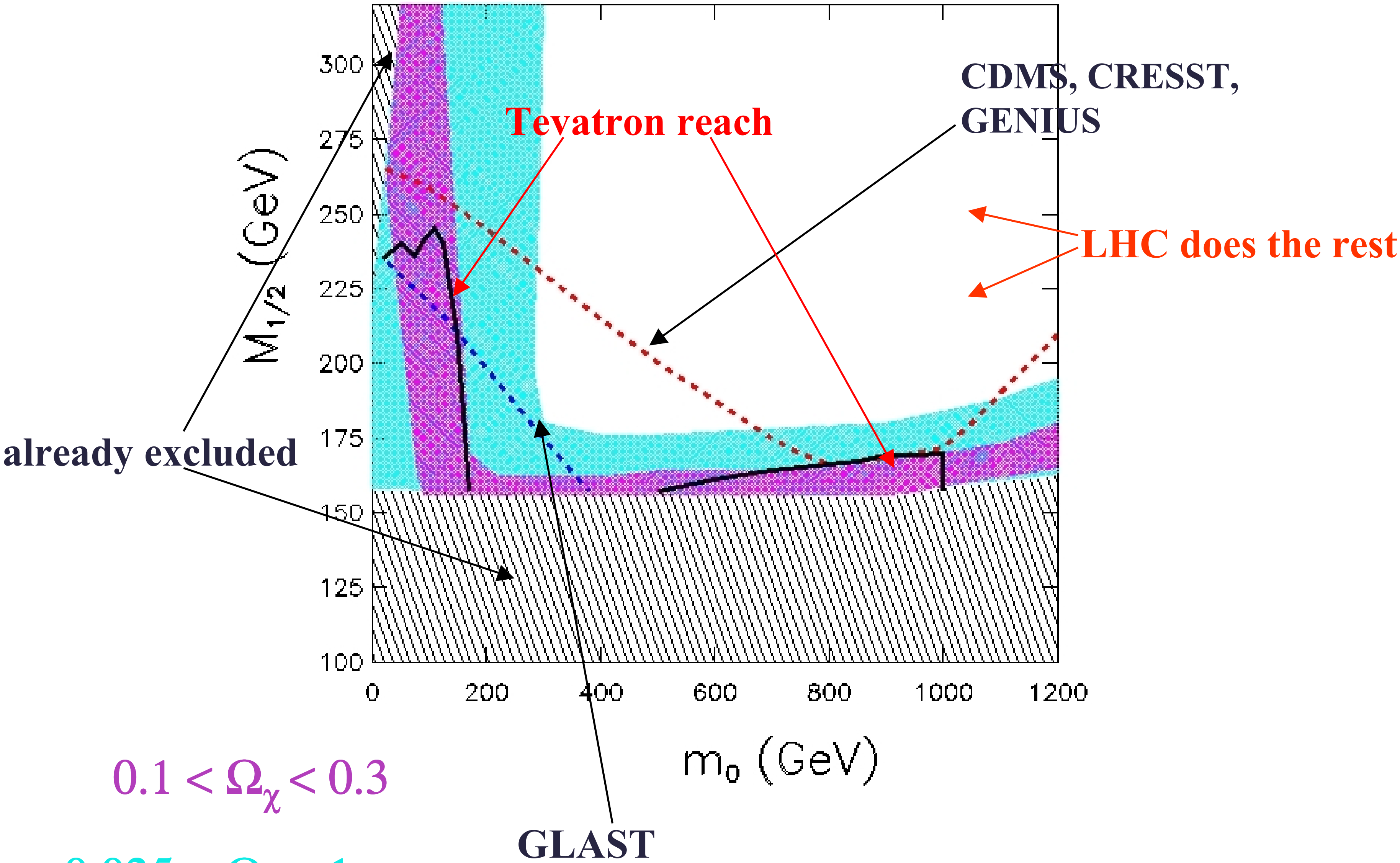
- ✓ neutralinos
- ✓ sneutrinos
- ✓ gravitinos
- ✓ 4^{th} generation neutrinos
- ✓ mirror partners
- ✓ messenger particles
- ✓ lightest Kaluza-Klein particles

neutralino dark matter

we are closing in fast on either discovery or exclusion!

there is a great degree of complementarity
between direct, indirect, and collider searches

J. Feng et al, L. Roszkowski et al, P. Nath et al, …



$0.1 < \Omega_\chi < 0.3$

$0.025 < \Omega_\chi < 1$

J. Feng, K. Matchev, F. Wilczek

How do we detect neutralino DM at colliders?

look at missing energy signatures:

QCD jets + missing energy

like-sign dileptons + missing energy

trileptons + missing energy

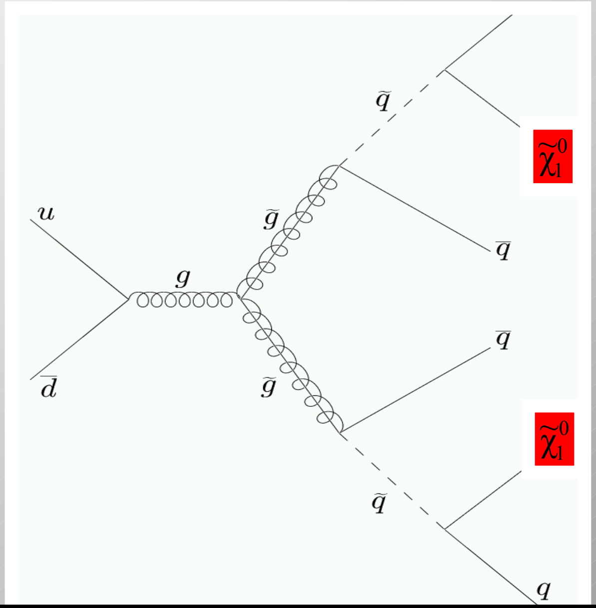
leptons + photons + missing energy

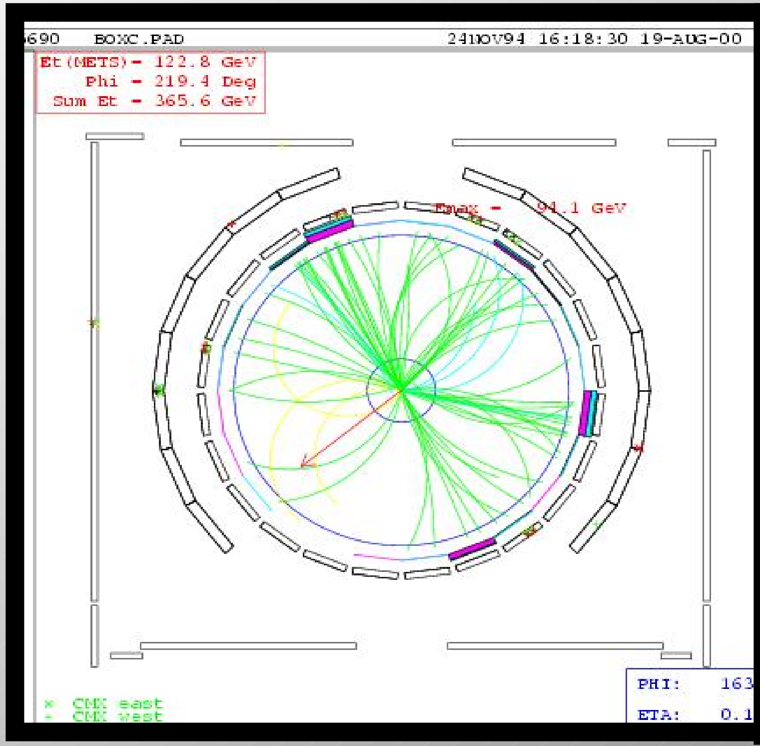
b quarks + missing energy

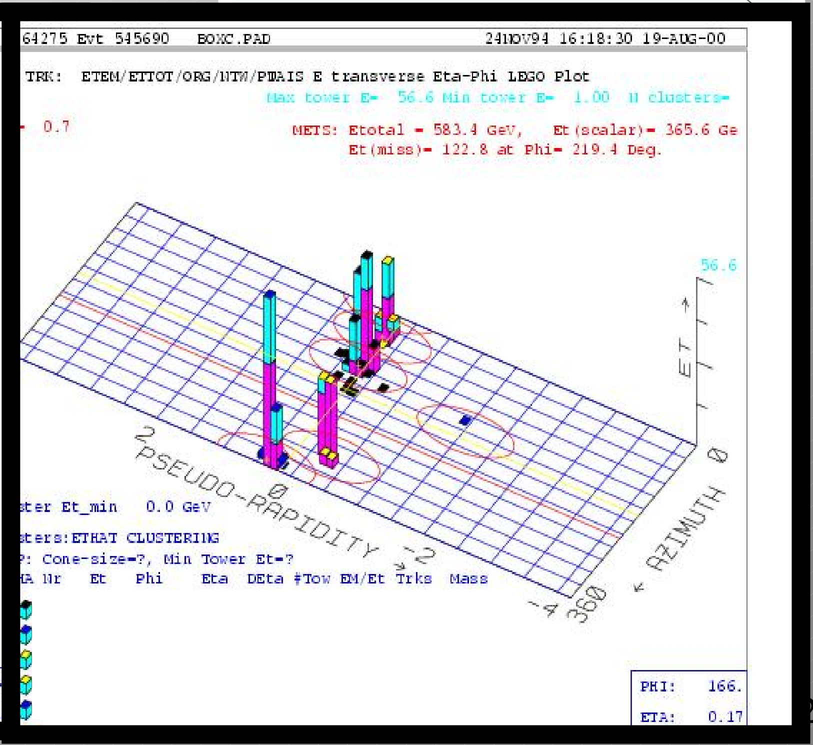
etc.

CDF 300 GeV gluino candidate:

gluino pair strongly produced, decays to quarks + neutralinos







how likely are we to discover neutralinos sooner rather than later?

ask some theorists:

susy – electroweak connection favors lighter gluinos to avoid tuning (G. Kane et al)

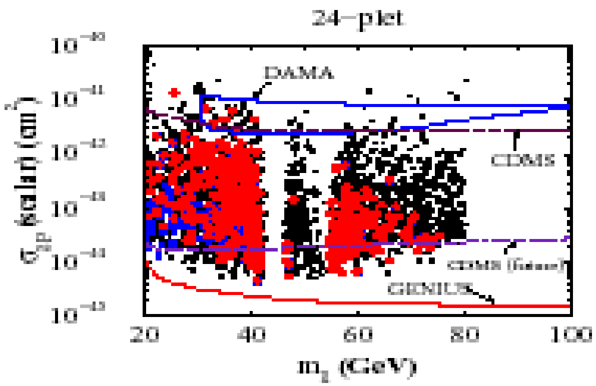
→ **look at models with nonuniversal gaugino masses**

e.g. models of Chattopadhyay Corsetti and Nath, which enforce b – τ unification, and impose muon g-2 constraint:

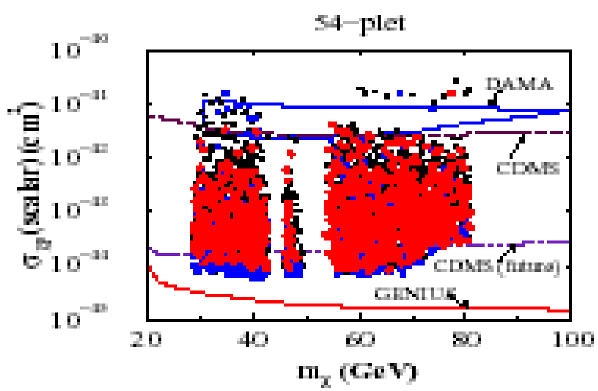
good news for the Tevatron

Table 1: Sparticle mass ranges for 24, 54, and 54′ cases

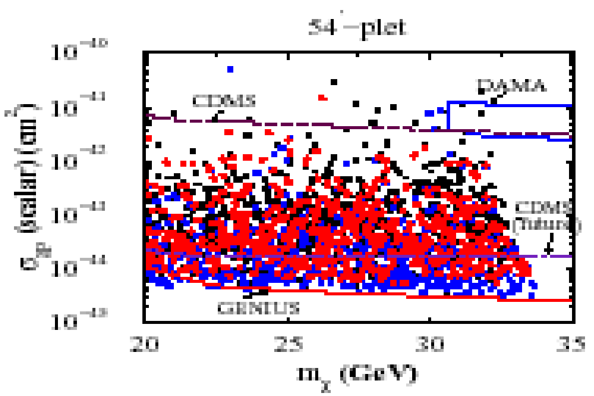
Particle	24 (GeV)	54 (GeV)	54′ (GeV)
χ_1^0	32.3 - 75.2	32.3 - 81.0	32.3 - 33.4
χ_2^0	96.7 - 422.5	94.7 - 240.8	145.7 - 153.9
χ_3^0	110.5 - 564.3	301.5 - 757.1	420.9 - 633.8
χ_4^0	259.2 - 575.9	311.5 - 759.7	427.6 - 636.9
$\chi_1^\pm$	86.9 - 422.6	94.6 - 240.8	145.8 - 153.9
$\chi_2^\pm$	259.9 - 577.2	315.1 - 761.6	430.7 - 639.2
$\tilde{g}$	479.5 - 1077.2	232.5 - 580.3	229.8 - 237.4
$\tilde{\mu}_1$	299.7 - 1295.9	480.5 - 1536.8	813.1 - 1196.3
$\tilde{\mu}_2$	355.1 - 1309.3	489.8 - 1482.7	835.3 - 1237.6
$\tilde{\tau}_1$	203.5 - 1045.1	294.2 - 1172.6	579.4 - 863.7
$\tilde{\tau}_2$	349.6 - 1180.9	422.6 - 1311.7	704.6 - 1018.3
$\tilde{u}_1$	533.6 - 1407.2	566.7 - 1506.4	822.9 - 1199.8
$\tilde{u}_2$	561.1 - 1443.0	584.7 - 1544.6	849.6 - 1232.6
$\tilde{d}_1$	535.1 - 1407.5	580.3 - 1546.2	845.1 - 1232.5
$\tilde{d}_2$	566.7 - 1445.2	590.1 - 1546.7	853.3 - 1235.2
$\tilde{t}_1$	369.9 - 975.2	271.5 - 909.6	513.7 - 819.9
$\tilde{t}_2$	513.7 - 1167.6	429.4 - 1107.4	599.4 - 848.2
$\tilde{b}_1$	488.2 - 1152.8	158.1 - 1042.0	453.2 - 749.9



(a)



(c)



good news for direct searches, too!

sneutrino dark matter

if sneutrinos are the LSP, they are dark matter

but there are problems:

LEP measurement of the invisible width of the Z boson
implies M_sneutrino > 45 GeV

but then expect low abundance due to rapid annihilation
via s-channel Z and t-channel neutralino/chargino exchange.

sneutrino dark matter

L. Hall et al (1997): susy with lepton flavor violation can split the sneutrino mass eigenstates by ~> 5 GeV, enough to suppress the annihilation processes

however, the same interaction seems to induce at least one neutrino mass ~> 5 MeV.

this is now excluded completely by SuperK + SNO + tritium beta decay.

it appears that sneutrinos are ruled out as the dominant component of CDM

gravitino dark matter

Large classes of susy models, i.e. gauge-mediated and other low-scale susy breaking schemes, produce light (keV) gravitinos that overclose the universe.

Fujii and Yanagida have found a class of "direct" gauge mediation models where the decays of light messenger particles naturally dilutes the gravitino density to just the right amount!

Such models have distinctive collider signatures

Kaluza-Klein dark matter

See talk by Tim Tait

If we live in the bulk of the extra dimensions, then Kaluza-Klein parity (i.e. KK momentum) is conserved.

So the lightest massive KK particle (LKP) is stable

Could be a KK neutrino, bino, or photon

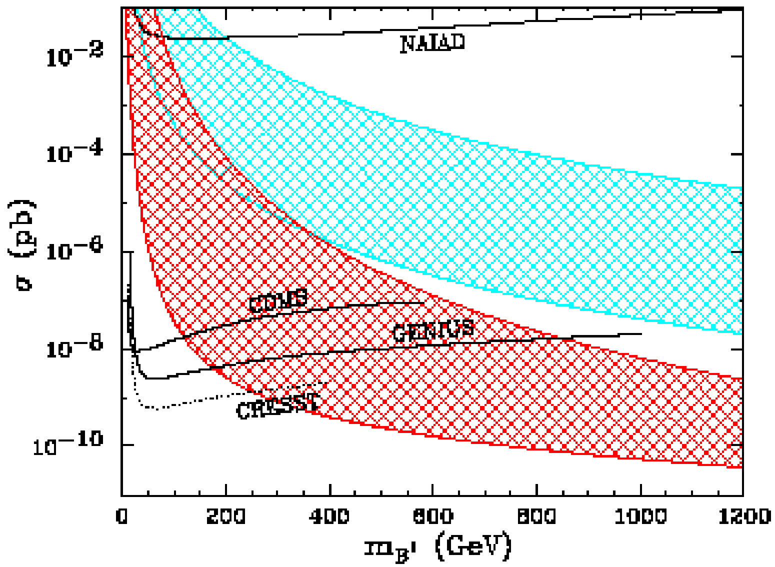
How heavy is the LKP?

Current data requires M_{LKP} ~> 300 GeV

LKP as CDM requires $M_{LKP} \sim 650 - 850$ GeV

the LHC collider experiments will certainly see this!

furthermore, we should have signals from direct searches, including positrons for AMS



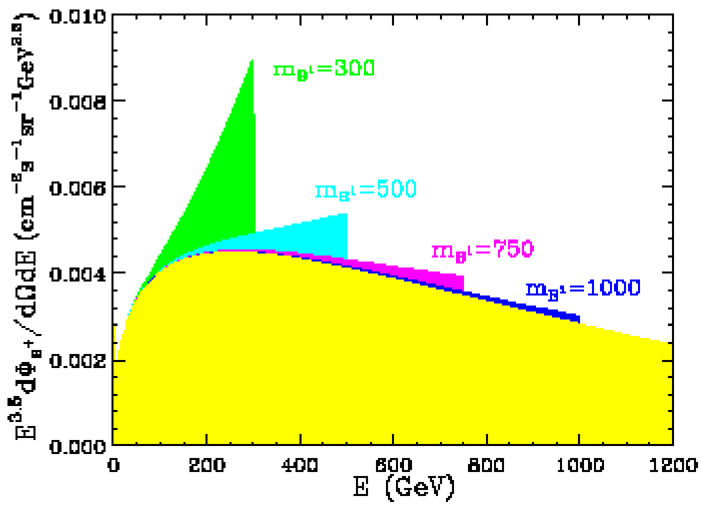


FIG. 2: Predicted positron signals (dark shaded) above background (light shaded) as a function of positron energy for $m_{B^1} = m_{e^1_L} = m_{e^1_R} = 100$, 500, 750, and 1000 GeV.

H-C Cheng, J. Feng, K. Matchev

colliders and baryogenesis

see talk by Mark Trodden

Baryogenesis requires new sources of CP violation
besides the CKM phase of the Standard Model
(or, perhaps, CPT violation).

B physics experiments look for new CP violation
by over-constraining the unitarity triangle

Susy models are a promising source for extra phases

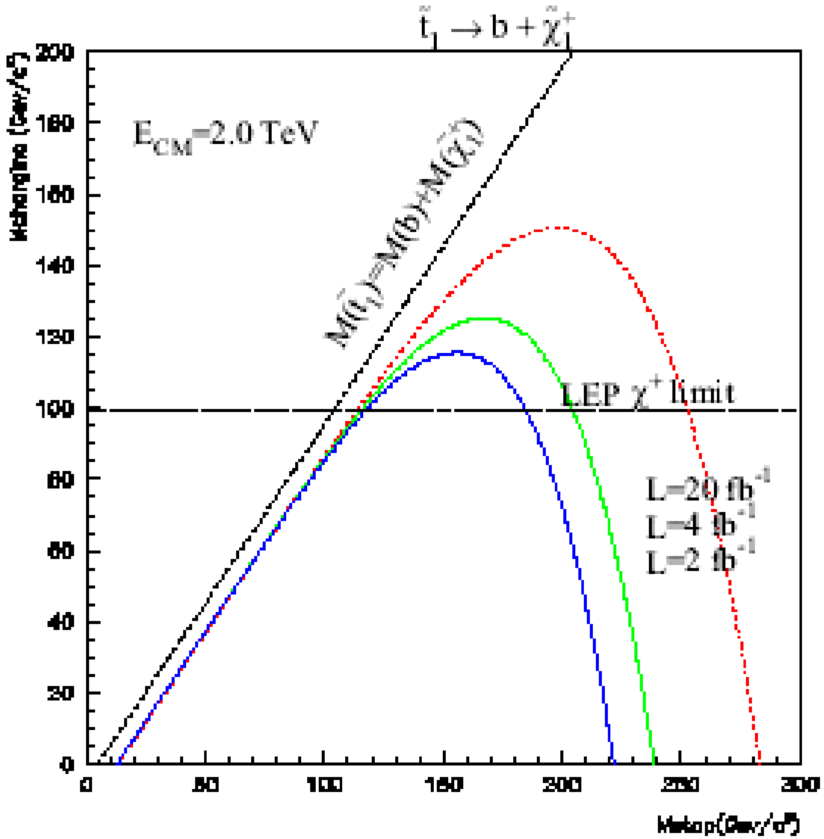
electroweak baryogenesis

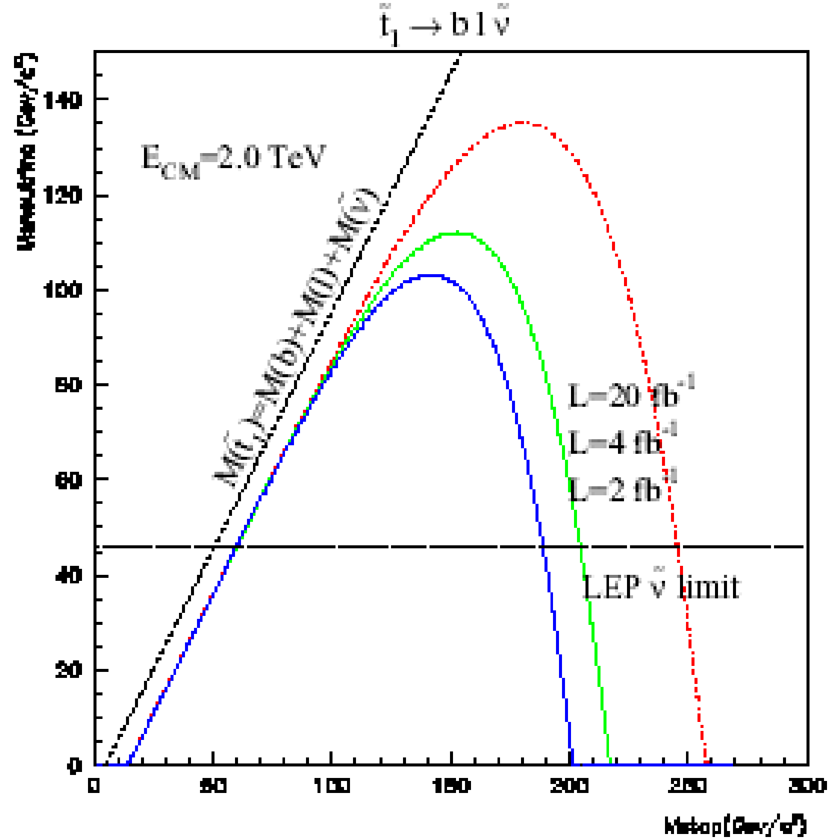
since colliders will thoroughly explore the electroweak scale, we ought to be able to reach definite conclusions about EW baryogenesis

EW baryogenesis in susy appears very constrained, requiring a Higgs mass less than 120 GeV, and a stop lighter than the top quark

M Carena et al

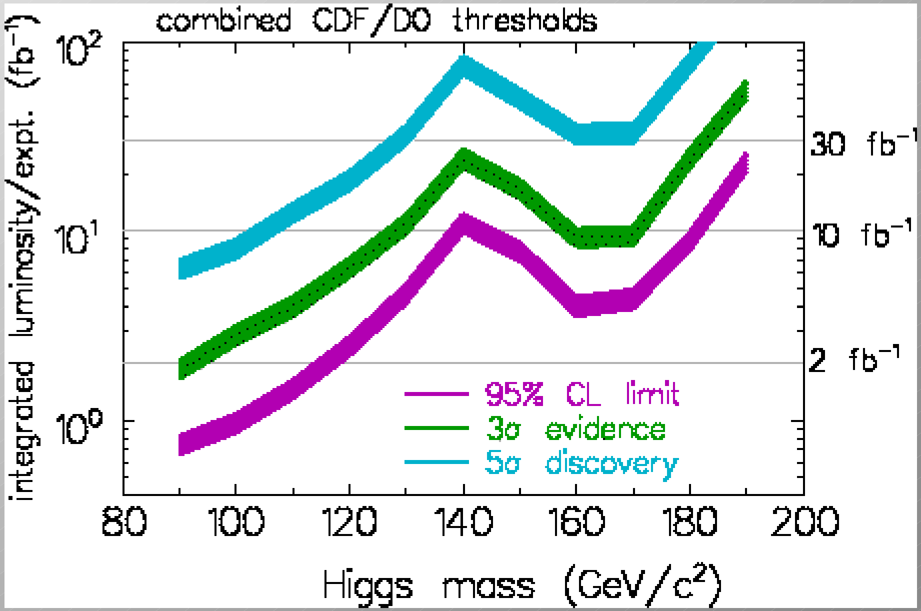
such a light stop will be seen at the Tevatron





At Fermilab we can also search for higgs bosons with mass up to 190 GeV, i.e. the preferred range from precision data, and are very likely to discover an MSSM higgs.

But it will not be easy



Superb performance of the accelerator and detectors (high luminosity) is essential

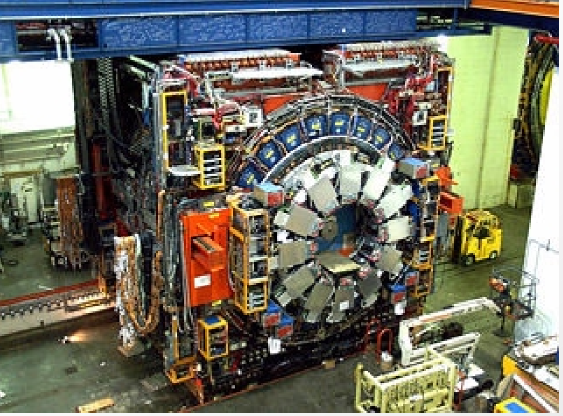
in warped extra dimensions models, modifications of the Friedmann equation can help electroweak baryogenesis:

$$H^2 = \frac{\rho(T)}{3m_{Pl}^2}(1+\alpha(T))$$

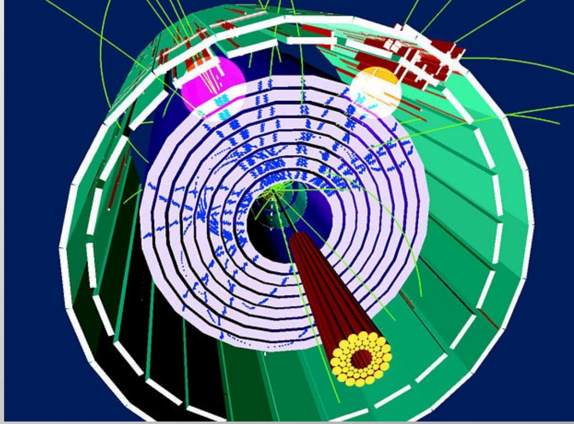
see talk by G. Servant

where

$$\alpha(T) = \mathcal{O}\left(\frac{\rho(T)m_{Pl}^2}{M^6}\right)$$



Summary



There is an excellent chance to discover the identity of dark matter in the next few years

There is an excellent chance for enlightenment about baryogenesis, especially EW baryogenesis, in the next few years

A discovery of either supersymmetry or extra dimensions (or both) at the TeV scale, will have profound consequences for cosmology